Georgia Institute of Technology

THE FACTORY OF THE FUTURE

by

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ABSTRACT

The Factory of the Future is examined from a material handling perspective. Opportunities and impediments for the Factory of the Future are addressed. Three major parameters in justifying factory automation are identified and assessed. Material handling objectives for the automated factory are listed. Key issues in stepping up to automation are discussed.

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INTRODUCTION

The Factory of the Future, also known as the automated factory, has captured the attention of both the business and technical community. The business press, computer magazines, and engineering publications have jumped on the automated factory band wagon. In some ways, the current fascination with the Factory of the Future is reminiscent of the focus given in recent years to the Office of the Future. Also, much of the focus on factory automation appear to be due to a "near paranoia" on the part of U.S. industry regarding Japan. Business leaders are traveling to Japan in record numbers to see first hand integrated factory systems.

Certainly, a number of impressive things are occurring in Japan. For example, the Yamazaki Machinery Works in Nagoya, Japan recently announced the opening of an automated factory. On the night shift, only a night watchman is present, while 18 machining centers continue to operate in the $18 million flexible manufacturing facility. On the day shift, people are used in the receiving area to operate the cranes used to load castings on material transporters. Also, people are used to perform tool sharpening and computer programming tasks.

Fujitsu Fanuc's new facility located near Mt. Fuji is also a near-automatic factory. On the third shift, robots are used to assemble robots.

This report includes much of the same material found in [5]; however, it extends the content of [5] to include a broader view of factory automation.

Several major corporations are attempting to position themselves to be suppliers of automated factories; others are assessing the role of the automated factory in their own manufacturing strategy. It is interesting to observe the increasing list of characters in the developing "automated factory" drama. Among those who seem to want to play leading roles are manufacturing equipment suppliers, material handling equipment suppliers, and computer system suppliers.

At a recent industrial engineering conference, a representative of a major machine tool supplier described the Factory of the Future as consisting of three major components: the manufacturing equipment, the material handling system, and the overall control system. Interestingly, he went on to state that, of the three, the one that could be specified most arbitrarily was the handling system! Alternately, some material handling system suppliers seem to believe their equipment is the best solution for the automated factory, regardless of the manufacturing equipment to be used. Not to be outdone, some computer system suppliers are promoting real time hardware and software packages for controlling the automated factory-independent of the manufacturing and material handling technology to be used.

Before proceeding further with a discussion of the automatic factory, it is important to define what we mean by the term. More specifically, it is important to emphasize what is not meant by the term. Namely, the automated factory is not the same as the automatic factory. The automatic factory is a peopleless factory. Automation and mechanization are dominate, but people are still needed in the automated factory to perform a limited number of direct tasks and a greater number of indirect tasks. People are needed in the automated factory to deal with unusual situations; it does not appear to be cost effective to design an automated system to handle exceptions. Instead, exceptions should be treated as exceptions!

JUSTIFYING THE AUTOMATIC FACTORY

Based on current assessment of the Factory of the Future, it appears that a hierarchical factory system will emerge, as illustrated in Figure 1. Based on decision points located strategically throughout the <u>automatic</u> factory, parts and subassemblies failing to meet stringent inspection standards will be routed to an automated factory designed to handle the exceptions! The automatic factory will be designed for either high volume/low variety or high value/low variety production; whereas, the automated factory will be designed for a wider variety of production requirements.

In assessing the opportunities for implementing an automatic factory, a V-3 analysis should be performed [7]. Namely, the <u>volume</u> of production, the <u>variety</u> of products to be produced, and the <u>value</u> of each product should be considered. Figure 2 summarizes the opportunities for justifying an automatic factory.

The opportunities appear to be the greatest when there exist high volume, low variety, and/or high value conditions. The indication of a medium opportunity suggests it might be possible to justify an automatic factory, but creative design will be essential. The indication of a low opportunity suggests it will be difficult, but not necessarily impossible, to justify a high degree of automation.

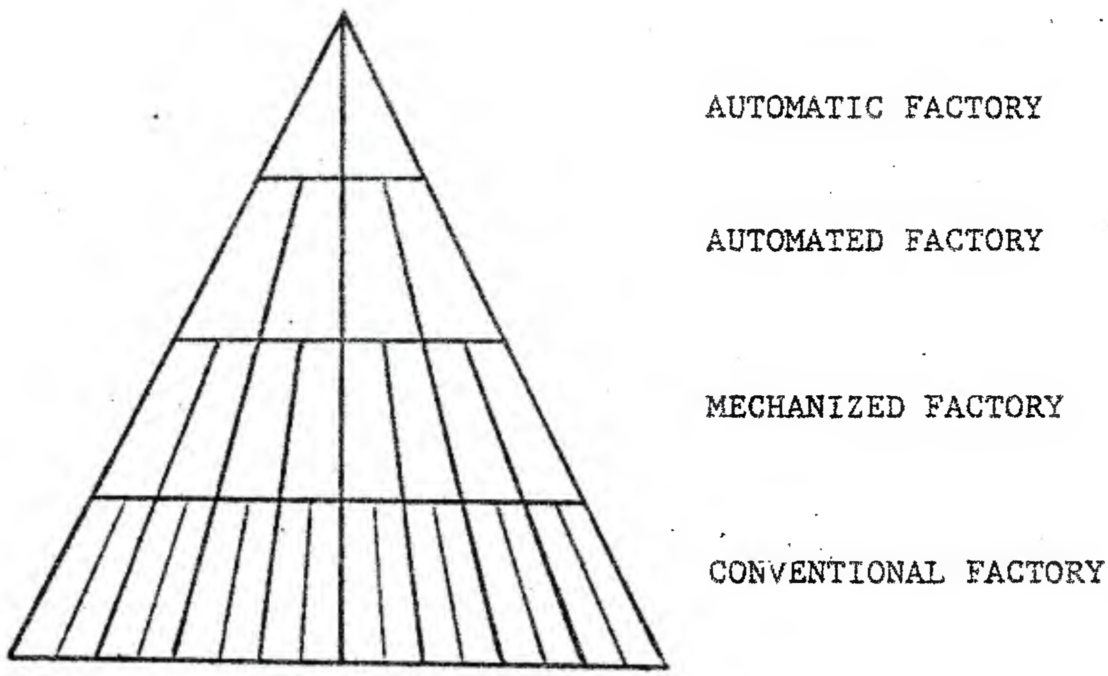

Figure 1. Factory System Hierarchy

VOLUME	VALUE	VARIETY: LOW	VARIETY: MEDIUM	VARIETY: HIGH
HIGH	H	HIGH	HIGH	HIGH
HIGH	M	HIGH	HIGH	MEDIUM
HIGH	L	HIGH	MEDIUM	MEDIUM
MEDIUM	H	HIGH	HIGH	MEDIUM
MEDIUM	M	HIGH	MEDIUM	LOW
MEDIUM	L	MEDIUM	LOW	LOW
LOW	H	HIGH	MEDIUM	MEDIUM
LOW	M	MEDIUM	LOW	LOW
LOW	L	LOW	LOW	LOW

Figure 2. V^3 Analysis: The Automatic Factory

Each situation must be evaluated separately; it is difficult to generalize concerning the opportunities to justify automation. In fact, not all would agree with the assessment given in Figure 2. For example, in [3], Lutz provides a profile of good and poor candidates for increased mechanization. His profile is given in Table 1. The factors considered by Lutz include relative market share, sales from new services, unionization, capacity utilization, real market growth, and standardized service versus made to order. He provides the following recommendation, "Give a business 3 points for any attribute that puts it on the good candidate list, 2 points for a percentage that puts it halfway, and 1 point for an attribute that categorizes it as a poor mechanization candidate. The average business would then receive 12 points, and the range will be from 6 points for a particularly doubtful candidate to 18 points for an excellent candidate. By looking at these relationships you can help determine what the payoff for mechanization might be for your firm." [3, p. II-6].

In many ways, the Factory of the Future is a misnomer. It suggests that the time for the automatic factory is in some distant time; it carries with it the connotation of the year 2000! It appears that most, if not all, of the hardware required for an automatic factory exists today. To bring the automatic factory to fruition, we should focus on factory automation and its role in tomorrow's factories.

Factory automation is being developed in three functional areas: manufacturing, engineering, and management. The approach used predominately today is to use automation technology selectively in each area to

Table 1. Profiles of Good and Poor Candidates for Mechanization [3]

FACTOR	GOOD CANDIDATES	POOR CANDIDATE
Relative market share	High (more than 60%)	Low (less than 25%)
Sales from new services	Low (less than 1%)	High (more than 10%)
Unionization	Low (less than 20%)	High (more than 65%)
Capacity utilization	High (more than 85%)	Low (less than 70%)
Real market growth	High (more than 6%)	Low (less than 1%)
Standardized service vs Made to Order	MTO	S

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form "islands of automation." Such "islands" must be bridged to form integrated factory systems.

ISLANDS OF AUTOMATION IN MANUFACTURING

The term islands of automation is one that is frequently used to describe the transition from conventional or mechanized manufacturing to the automated factory. Interestingly, some use the term as though it were a worthy objective to create islands of automation. On the contrary, the creation of such islands can be a major impediment to the integrated factory.

Manufacturing examples of islands of automation include numerically controlled machine tools; programmable controllers; automated storage/retrieval systems for storing work in process, tooling, and supplies; robots for assembly, painting, and welding; lasers for cutting, welding, and finishing; sensors for test and inspection; smart carts and conveyors for moving material from work station to work station; and flexible machine systems. They are often purchased one at a time and justified by cost reductions.

To integrate the islands it is necessary to link several machines together as a unit. For example, "a machine center with robots for parts loading and unloading can best be tied to visual inspection systems for quality. Computer numerical control machine tools can all be controlled by a computer that also schedules, dispatches and collects data. Selecting which islands to link can be most efficiently pursued on the basis of cost, quality and cycle time benefits" [1].

In some cases the islands will be very small (e.g. an individual machine or work station). In other cases the islands might be department-sized.

As an example of the creation of relatively small islands of automation, consider an appliance manufacturer who installed a number of robots along an existing assembly line. The resulting labor reduction generated a cost savings; the robots were certainly justified economically. However, an opportunity was missed: to increase productivity for the total system. Materials were delivered to the robots and removed from the robots using the existing material handling system. Because the production rates for the robots differed from the manual rates, materials were stacked on the floor around the robots and in the aisles. From a myopic point of view, the robot was impressive; whereas, from a systems point of view, an island of automation had been created.

An example of a relatively large island of automation was observed in a gearbox plant for a truck manufacturer. Castings were fed from a magazine to a robot, which subsequently fed the casting to each of three (3) machines and then placed the semi-finished part on a conveyor. The conveyor delivered the part to a second robot, which fed the part to each of three (3) additional machines and then placed the semi-finished part on a second conveyor. The part was delivered to a third robot, which fed the part to each of three (3) more machines and placed the finished part on a peg-rack dolly for pick-up and delivery by tugger to a storage area. Three islands of automation had been linked together to form a much larger island.

Interestingly, the castings were delivered in a wire basket to the first robot by lift truck. The castings had come from the foundry in a near-by building. At one point the castings were on a belt conveyor positioned and spaced in such a way they could have been automatically placed in the delivery container in a controlled faction. However, they were dumped into the wire basket. Consequently, at the gearbox building someone had to reach into the wire basket, grasp a casting, orient it properly, and place it in the magazine that fed the first robot. Why didn't the foundry place the castings in the basket so that they could be removed automatically? "It wasn't their problem!"

(Many management systems appear to represent major impediments to the design of integrated systems. Evaluating managers strictly on their cost center performance seems to discourage incurring small costs to generate big savings downstream.)

From a systems viewpoint, islands of automation are not necessarily bad, so long as they are considered to be interim objectives in a phased implementation of an automated system. However, to obtain an integrated factory system, the islands of automation must be tied together or linked. An obvious approach that can be used to physically "build bridges that join together the islands of automation" is the material handling system. Likewise, information bridges can be provided through the control system.

MATERIAL HANDLING SYSTEM OBJECTIVES

In designing material handling systems for the automated factory, the following objectives should be considered:

- create an environment that results in the production of high quality products;
- provide planned and orderly flows of material, equipment, people, and information;
- design systems that can be easily adapted to changes in product mix and production volumes;
- design a layout that accommodates expansions in product mix and production volumes;
- reduce work-in-process;
- provide controlled flow and storage of materials;
- integrate processing, inspection, handling, storage, and control of materials;
- eliminate manual material handling at work stations;
- eliminate manual material handling between work stations;
- utilize the capabilities people have from the neck up, not the neck down;
- deliver parts to work stations in pre-determined quantities and physically positioned to allow automatic parts feeding to machines;
- deliver tooling to machines in a controlled position to allow automatic unloading and automatic tool change; and
- utilize space most effectively, considering overhead space and impediments to cross traffic.

MATERIAL TRACKING

A key ingredient for the automated factory is the shop floor control system. One element of a total shop floor control system is the material tracking system, which passes information about the material to such automated equipment as machine tools, robots, storage/retrieval systems, sortation conveyors, palletizers, and guided vehicles.

Two approaches used to perform material tracking are <u>continuous tracking</u> and <u>interrupted tracking</u>. With continuous tracking a single input external to the system is required. The input could be keyed in manually or read automatically from magnetic or optical codes on the material. Following the initialization of the tracking system, the material is tracked continuously based on feedback from the equipment/material interfaces, rather than the material itself.

With interrupted tracking, "snapshots" of the material are taken periodically by automatic identification equipment. Between "reads" by the automatic identification system, the material can be considered to be in a tunnel and is invisible to the control system. However, its status is known and available in real time. Feedback is not provided to the control system from the equipment/material interface. Rather, information is transmitted to the automated equipment by the control system, based on information received from the material.

In both the continuous and interrupted tracking system, the computer system serves as the courier of information from the material and/or the equipment/material interfaces "upstream" to the automated equipment "downstream." Large data bases and relatively sophisticated computer systems are required for continuous tracking; alternately, interrupted tracking typically places fewer demands on the computer system.

A recent development in interrupted tracking has resulted in the material serving as the courier of data from the computer system and the equipment/material interfaces "upstream" to the automated equipment "downstream." Referred to as PREMID (Programmable Remote Indentification) the Swedish developed product utilizes a "smart badge" on the material for dynamic storage of information. At strategically located data transmission points, microwave transmitters transmit data to the badges, which can receive, store, and transmit information. In turn, when the material arrives at an equipment/material interface relays information to the automated equipment. The material handling network becomes a part of the information network with this method of material tracking.

MATERIAL HANDLING EQUIPMENT

What material handling equipment will be included in the automated factory? The answer to the question obviously depends on the material characteristics, flow requirements, and constraints imposed by the facility and manufacturing equipment. A case can be made for practically all unmanned material handling equipment playing a role in the automated factory.

At this time the leading candidates for transporting material between specified points appear to be belt, chain, and roller conveyors, towline and trolley conveyors, monorails, and automated guided vehicles. Because of the desirability of keeping material under control physically by having it properly positioned and oriented for automatic loading/unloading, specially designed fixtures, tote boxes, containers, and/or slave pallets will be used throughout the system.

Work in process will likely be stored either in miniload storage/retrieval systems and carousel storage/retrieval systems depending on its size. However, computer controlled lift trucks also will be used to perform storage/retrieval operations in aisle-to-aisle applications.

Monorail systems will be used for both storage and material transport. The monorail system in the automated factory will involve microprocessor controlled carriers that operate much like the AGVS. The primary distinction between the monorail system of the future and the AGVS is the former will be installed overhead. Because of its ability to be installed in 3-dimensions, the monorail can represent a highly flexible alternative to the AGVS. However, installation cost for the monorail will be an economic factor to contend with.

A monorail system will consist of both powered and unpowered carriers. Using computer controlled people mover systems as a model, the monorail system can provide automatic switching and traffic control to allow a high degree of activity on relatively short paths. Automatic transfers of material will be possible between carriers on the monorail just as packages can be automatically transferred between trains at specified transfer points.

The automated factory will include improved recognition systems based on vision, sonar, laser, and microwave technology. Additionally, voice encoding will play an important role in the Factory of the Future.

Robots and robot-like devices will perform most of the material handling at the work station.

ROBOTICS

Robots are definitely in! The current robot craze is similar to the computer craze of the 50's and 60's. In fact, it is hard to find a firm today that neither has one nor is not contemplating acquiring one. Furthermore, top management's fascination with robots has led some plant managers to conclude that they had better install a robot somewhere, whether they need it or not.

Many opportunities for using robots are actually micro and macro materials handling applications. For example, robots might be used to perform case packing, palletizing, depalletizing, sortation, parts loading and removal, tool changing, and materials delivery.

"Mechatronics" is a term used in Japan to refer to robotics; it denotes a combination of mechanization and electronics. A spokesman for Japan's robot industry listed several types of "blindness" for the early generation of robots. Expanding and amplifying the list yields the following areas for improvement:

- target blindess, the need to physically control material in terms of position and orientation in order to perform simple pick-and-place operations;
- material blindness, the need to distinguish between different types of material;
- equipment blindess, the need to sense the locations of other

equipment and to communicate with the materials handling system and the processing system;

- people blindness, the need to sense the locations of people and to communicate with people;
- environmental blindness, the need to sense and adopt to changes in the environment;
- deterioration blindness, the need to detect deterioration in itself and its performance and to perform self-correcting operations based on the feedback;
- interface blindness, the need for a smooth hand-off of material and transfer of responsibility; and at the interfaces between robots and material/equipment/people;
- communication blindness, the need to communicate with other robots and to be integrated in the factory system, rather than function as a stand-alone local processor [6].

The robot family of the future undoubtedly will have a hierarchy of skill levels. There will exist a wide range of skills. As with people, not all robots will be the same. Some robots will have extremely limited sensory capabilities, others will be quite sophisticated.

Currently, robots are seldom integrated into the factory system due to an inability to communicate with the rest of the factory system. The future robot family will function as a part of an integrated system because of the communication system that must exist. Specifically, a universal language must be developed to allow robots to communicate with one another, regardless of the manufacturer. Furthermore, they also must communicate with manufacturing equipment, materials handling equipment, and the management information system.

A common communication system for robots will be needed in the future. It is anticipated that each level of robots in the hierarchy will have its own unique language. After all, scientists, engineers, accountants, manufacturing managers, and computer systems analysts have their own unique terminology or "language"; yet they can communicate with one another by using a common language. The same will need to hold true for robots.

AUTOMATION TECHNOLOGY FOR ENGINEERING AND MANAGEMENT

As noted by Beavers [1], the use of automation technology in the engineering function has probably received the most publicity because of the use of computer-aided design (CAD). The use of interactive graphics to automate the drafting and design articulation process has had a dramatic impact on design productivity.

In addition to automated drafting, the analysis and synthesis processes of engineering have become computer-aided. Beavers [1] points out another critical process in engineering is the test and evaluation of a designed prototype. Automating the feedback from prototype testing can speed up the design process significantly.

Beavers observes, "CAE is the first example of automation interaction in the factory environment. Computer-aided engineering or CAE is the integration of computer simulation, interactive graphics, and disciplined design philosophies into the total engineering process. The goal of CAE is to optimize the collaboration of people and automation in the practice of engineering" [1].

He goes on to state, "In the ultimate computer-aided engineering scenario, designers will be able to observe and articulate their designs interactively in three dimensions and in color. They will be able to describe the minutest of details about their design in a computer data base. They will be able to analyze the performance of their designs of discrete components as well as of total systems using computer simulation. Several interactions of the design and review process can occur before a prototype design has to be physically built. In certain situations, a physical prototype is not even necessary. Once a prototype is built, testing of that prototype can be computer controlled and the results returned to the design data base to assist the human designer in modifying his engineering approach" [1].

For many companies, automation holds the key for the 80's. However, with increased automation comes increased dependence on reliable computing systems. No-fault, nonstop, fail-soft processing will be an increasing requirement for the 80's. As Beavers put it, "As the industrial environment becomes more automated, as the critical paths through the engineering and manufacturing functions become shorter and more time dependent, and as the individual machines in the factory become more intelligent, the collection, transfer and management of data becomes more important. There have been significant advances in materials resource planning computer software, and in shop floor data collections systems in recent years. However, the need for local area networking, high level data communication protocols and data base management systems have become more urgent as the state-of-the-art in manufacturing and engineering advances" [1].

Real time control systems and MRP systems will play an important role in the management of the automatic factory. MRP, material requirements planning, and its enhancement, manufacturing requirements planning (MRP-II), will be coupled with shop floor control systems to allow real time management systems to be installed.

Enhancements in factory automation will continue to occur as improvements are made in its foundation technologies. According to Beavers [1], the technologies which tend to drive factory automation include

- process controls,
- communication systems,
- intelligent systems,
- sensory systems, and
- software systems

In viewing the challenges in implementing the Factory of the Future, Beavers observed, "Possibly the single greatest challenge in applying factory automation will be to have discipline and patience to understand, describe, and plan for its use. In the Factory of Today, many of the key functions are performed by rational, flexible and emotional human beings. Many of the decisions that are made daily by our 'distributed human intelligence' systems are what keep our ill-planned or inefficient factories working. As we apply automation in today's factory, we must anticipate the contingencies that could be needed so that the 'distributed machine intelligence' can deliver more dependability.

"The ultimate integration of technology and application knowledge will continue to evolve over the remainder of this decade. Where exactly factory automation will lead will depend a lot on the speed of innovation and pressures of the marketplace and economy. Much of the momentum of innovation will come from forward thinking executives and engineers, who have been applying a long time horizon to automation planning.

"Factory automation will not be easy, and it will not come overnight. The real issue is whether a firm will continue its past practice of using the 'island' approach - in effect, applying bandages to a patient requiring intensive care - or using a well planned systems approach. We believe that this is what must be done and we are prepared to fill that need" [1].

Along the same lines, Palmer [4] expressed the following view, "The only task remaining, it seems to me, to erect and operate an automatic factory, is to determine the method by which these disparate technologies must be integrated. The point I wish to make is that the obstacle to the reality of the automatic factory is a problem of how to get it done." He then concluded, "I submit the real problem remains the problem of integration."

STEPPING UP TO AUTOMATION

With the increased focus on automated materials handling an implementation plan for automation should be developed. The old addage, "eat an elephant one bite at a time," certainly applies in stepping up to automation [8].

Seven issues come to mind in planning for the transition toward increased automation. Each will be treated briefly.

1. Evolutionary change or revolutionary change? Few organizations appear to have been successful in effecting revolutionary change by introducing radically new technolgy and gaining employee acceptance. For revolutionary change to be successful, a strong commitment is required from all levels of management. Since evolutionary change is most prevalent, it is important to establish a long range plan in order to set evolutionary changes in the desired direction. Each capital dollar should be invested in a direction consistent with the long range goal.

2. Islands of automation or integrated systems? As mentioned previously, the design of integrated systems is advocated, rather than the creation of islands of automation. However, the realities of capital funding often require that islands of automation be created in stepping up to automation. For this reason, it is critically important for the "islands" to be created with the future "bridges" needed to integrate the system already in mind.

3. Flexible automation or rigid automation? Three key issues in designing materials handling systems for the 80's are flexibility, integration, and control. Each becomes increasingly important in the face of perhaps the most important

issue, change! If requirements for handling, storing and controlling materials are anticipated to change significantly, then flexible automation is preferred; on the other hand, if relatively little change is anticipated, then rigid automation should be considered.

4. "Tried-and-true" technology or "latest-and-greatest" technology? In stepping up to automation many organizations prefer to stick to proven technology. If all organizations reacted that way, the state-of-the-art would still be "lifting that barge and toting that bale." International, as well as domestic, competition makes it imperative that we continue to push forward the state-of-the-art. It is disturbing that so many users, suppliers, educators, and consultants claim new technology is not needed. Many leading U.S. corporations have been using today's "leading edge technology" for a decade; their international competitors are engaged in searching for new, cost-effective ways to move, store, and control materials.

5. Automated factory or automatic factory? In an earlier section, the distinction was made between the automated factory and the automatic factory. Depending on the value, volume, and variety of production, the automated factory will be preferred to the automatic factory. Ironically, the recent announcement of the construction of a new factory in Florence, Kentucky by the Yamazaki Machinery Works of Japan insures that there will be a highly automated "focused factory" in the U.S.

6. Short-term focus or long-term focus? Despite the criticism in the business press of the short-term focus of U.S. managers versus the long-term focus of Japanese managers, it is not likely that the U.S. situation will change radically. Demands from stockholders for dividends and/or growth put tremendous pressures on managers to focus on short-term gains. The challenge facing the materials handling system designer is to design a long-term system and then to develop an implementation plan in which each step up to automation is justified using short-term ROI or payback requirements.
7. "Off-the-shelf" technology or customized systems? Today's economic climate is forcing increased standardization in both hardware and software. Few can afford to "roll your own" and demand customized systems. Interestingly, off-the-shelf AS/RS is available in Japan. The life cycle benefits of standardized systems include reduced purchase prices and installation costs, but also the benefits of quicker delivery of the system. To satisfy diverse requirements, standardized components are combined in diverse ways to obtain packaged systems. Modular systems are expected to become dominant in the future to facilitate stepping up to automation.

Many issues face the materials handling system designer in stepping up to automation. Seven have been considered briefly. Undoubtedly, there are many others, e.g. in-house computer expertise, attitudes toward automation, past experiences with automation, competitor's response to automation.

In considering the proper amount and type of automation technology, it is important to remember that customers aren't interested in technology for technology's sake. Rather, they want quality, reliability, performance and service at the lowest possible price.

SUMMARY

In summary, the hardware required for the Factory of the Future exists today for many applications. The missing ingredients are not believed to be hardware components; rather, what appears to be lacking is an economic environment making it cost effective to automate all factory operations. As hardware and software costs reduce relative to humanware costs, the economic viability of the automatic factory improves.

For the automatic factory to become a reality, concern for the material handling system must exists among the product designers and the process designers. Concern for material handling cannot be an afterthought. It is a "key piece of the automatic factory puzzle. Material handling and the automatic factory go hand-in-hand. The automatic factory will not exist without the best technology in material handling" [4].

Products must be designed for both manufacturability and handleability. Specifically, the shapes and sizes of materials, parts, tooling, sub-assemblies, and assemblies must be carefully considered to insure that automatic transfers, loading, and unloading can be performed.

To facilitate the consideration of material handling in designing the automated factory, product designers, process designers and material handling systems designers must work together.

As high technology areas emerge, many will find applications in the handling, storage and control of material. Europe has led in the development of hardware technology, and the United States has led in the development of controls technology. However, the Japanese appear to be the leaders in applying new technology to factory systems. Their systems discipline is such that they "make it work."

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